Tidal and Diel Variations in the Abundance of Larval Fishes in Botany Bay, New South Wales, with Emphasis on Larval Silverbiddy *Gerres ovatus* (Fam. Gerreidae) and Gobies (Fam. Gobiidae)

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Surface plankton samples were collected from an area of strong tidal flow in Botany Bay, during early autumn 1981, to examine tidal and diel variations in the abundance of larval fishes. The sampling program was restricted to one 24 hour period, and yielded 2,898 larvae consisting of 30 distinct larval types from 21 families. Larval gobies (Fam. Gobiidae) and silverbiddy *Gerres ovatus* (Fam. Gerreidae) dominated the assemblage, and together accounted for 82.5% of the standardized total catch. On the selected sampling day the composition of the larval assemblage differed at either end of the tidal range. Gobiid larvae were more abundant at low tide both day and night, whereas abundances of *G. ovatus* were greater at high tide both day and night. Night catches of gobiid and *G. ovatus* larvae were greater than day catches. The great majority of *G. ovatus* larvae had deflated gas bladders during the day and inflated gas bladders at night. The limitations of these findings are acknowledged; due to the short sampling period it is possible that effects of other variables were confounded with effects of the main factors being tested.

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INTRODUCTION

Although the nursery function of Australian estuaries has been studied (Lenanton, 1977; Robertson, 1980; SPCC, 1981; Young, 1981; Bell *et al.*, 1984; Middleton *et al.*, 1984) little is known about larval fish distributions or the factors which affect larval recruitment in these estuarine areas (Steffe and Pease, 1988).

The common problem facing both recruiting larvae and those already in the estuary is how to maintain their position in the estuary and avoid being flushed out on the ebb tide. Weinstein *et al.* (1980) proposed that successful recruitment and/or retention in a stratified estuarine system involved selective vertical migrations by larval fishes in conjunction with changes in tide and photoperiod. There is also evidence that the larvae of other estuarine dependent species respond to tidal or diel stimuli, or both (Fore and Baxter, 1972; Graham, 1972; Eldridge, 1977; Melville-Smith *et al.*, 1981; Fortier and Leggett, 1982; Norcross and Shaw, 1984; Roper, 1986), but the mechanism(s) by which larval fishes achieve this are poorly understood.

Here, the findings of a sampling program designed to analyse variation in larval fish abundances with respect to changes in tidal and diel conditions are reported. The main question asked was: on the selected sampling day did larval fish abundances at the surface vary with respect to changes in tide and/or diel conditions?

MATERIALS AND METHODS

Study Area

Botany Bay (34°01′S, 151°11′E) is a large, semi-landlocked estuary on the east coast of Australia (Fig. 1). It is dominated by ocean swell and wind waves (Roy *et al.*, 1980), is vertically well mixed (Rochford, 1951), and at most times is best described as a marine embayment.

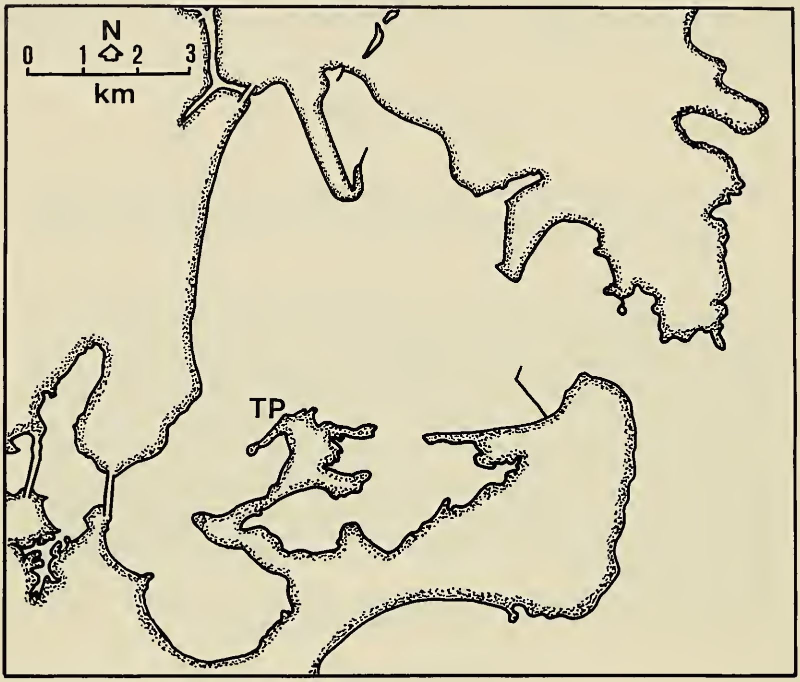

Fig. 1. Map of Botany Bay showing location of sampling station. Abbrev.: TP = Towra Point.

A sampling station (Fig. 1) was selected off Towra Point because of its position in the main tidal stream and its close proximity to large *Posidonia australis* and *Zostera capricorni* seagrass meadows, and an extensive mangrove stand. These habitats are important fish nursery areas (Bell *et al.*, 1984; Middleton *et al.*, 1984). Samples were collected during March (early Autumn) as juveniles of many economically valuable fishes are most abundant in the Bay shortly after this period (Bell, 1980; SPCC, 1981; Bell *et al.*, 1984; Middleton *et al.*, 1984). The maximum depth at the sampling station was about 4m.

Field Procedures

The sampling program was designed to analyse variances in larval fish numbers between stage of tide (high vs low) and diel condition (day vs night) at one station. The design was orthogonal and required that both high and low tides be sampled during daylight, and at night. High and low tide were defined as a two hour period with the tidal prediction at its centre. Four replicate samples were collected at each consecutive high and low tide over the 24 hour sampling period. Tidal height ranged from 0.2-1.6 m above I.S.L.W. during the sampling period.

Day sampling commenced 40 minutes after sunrise (05.57h) on 19 March 1981 and night sampling commenced one hour after sunset (18.09h). Plankton samples were collected from a small (4m) boat using a net with a square mouth (area $0.25m^2$), a mesh of 500 μm, and a length of about 2.5m. The net was towed in a circular path at the surface at a constant speed of about 2m sec^{-1} for 5 minutes (± 5 sec.). This procedure kept the net out of the engine wash and thus avoided unnecessarily increasing net escapement. A General Oceanics (model 2030) flowmeter was used to measure the volume of water filtered. Volume filtered per tow averaged $133.7m^3$ (s.d. 13.2). A salinity (± 0.1°/₀₀) and water temperature (± 0.2°C) reading was taken during each of the consecutive tides sampled.

Samples were preserved immediately after collection in 5% Steedman's preservative and were sorted entirely under a dissecting microscope. All larval fishes were identified to the lowest possible taxonomic level and then stored in 4% buffered formalin. Standardized larval abundances are expressed as the number of larvae per $100m^3$ water filtered. Terminology follows the definitions of Leis and Rennis (1983).

Size Distribution and Gas Bladder Inflation Incidence

Some 200 day-caught and 200 night-caught larvae of *Gerres ovatus* and of gobiids were randomly selected. These larvae were measured to the nearest 0.1 mm using a dissecting microscope with mounted ocular micrometer. Notochord length was recorded for preflexion and flexion stages whilst standard length was measured for postflexion stages. The numbers of larvae with deflated, or inflated gas bladders were then recorded separately for day-caught and night-caught *G. ovatus* only. This was easily done as the gas bladder in this species is clearly visible when inflated. This procedure was not repeated for gobiid larvae as they have a permanently inflated gas bladder.

RESULTS

The sampling program yielded 2,898 larval fishes consisting of 30 distinct larval types from 21 families (Table 1). Silverbiddy *Gerres ovatus* and gobiid larvae dominated the larval fish assemblage. *G. ovatus* larvae accounted for 31.3% of the standardized total catch whilst gobiids (four spp.) made up 51.2% of this total. The remaining 19 families contributed 17.5% of the standardized total catch but were not sufficiently abundant, or were present in too few samples, to warrant statistical analysis (Table 1).

More *Gerres ovatus* were caught at night and during high tide (Fig. 2**a**, Table 2). The interaction term was not significant. Similarly, significantly more gobiid larvae were caught at night, however unlike *Gerres ovatus*, significantly more gobiids were caught during low tide (Fig. 2**b**, Table 2). There was no significant interaction (Table 2).

Total fish larvae reflected the contrasting patterns of *Gerres ovatus* and gobiids. Night catches were significantly greater than day catches, but there was no significant tidal effect or interaction (Fig. 2**c**, Table 2).

The length frequency of night-caught *Gerres ovatus* larvae was similar to that for day caught larvae (Kolmogorov-Smirnov test, Dmax. = 0.075, $p >>> 0.05$) (Fig. 3**a**). Ninety-eight percent of day-caught larvae (n = 200) were found to have deflated gas bladders and ninety-five percent of night-caught larvae (n = 200) had strongly inflated gas bladders.

The length frequency distribution of gobiid larvae caught during daylight was significantly different to that of gobiids caught at night (Kolmogorov-Smirnov test, Dmax. = 0.23, $p < 0.001$) (Fig. 3**b**). In contrast to *G. ovatus*, more larger gobiid larvae were taken at night.

Salinity and water temperature did not fluctuate greatly during sampling (temp.

22.8-24.0°C; sal. 32.7-34.0‰) and rainfall had not been reported for the previous ten days in the area (Bureau of Meteorology, 1981).

TABLE 1

Number of distinct larval types, occurrence, and the percentage of the standardized total catch for each taxon in the larval assemblage. Note that each larval type may not be monospecific

Taxon	No. Larval Types	Occurrence (Max. = 16)	% Standardized total catch
Gobiidae	4	16	51.2
Gerreidae	1	16	31.3
Ambassidae	2	15	4.7
Syngnathidae	4	16	3.7
Blenniidae	2	12	1.5
Sillaginidae	1	8	0.7
Sparidae	2	7	0.7
Monacanthidae	1	7	0.5
Carangidae	1	5	0.4
Atherinidae	1	4	0.3
Anguilliformes	1	3	0.2
Clupeidae	1	5	0.2
Hemirhamphidae	1	1	0.1
Platycephalidae	1	1	0.1
Pempherididae	1	3	0.1
Soleidae	1	3	0.1
Tetraodontidae	1	3	0.1
Scorpaenidae	1	1	0.1
Mugilidae	1	1	
Sphyraenidae	1	1	
Callionymidae	1	1	
Damaged larvae	—	16	4.0

TABLE 2

F ratios and significance levels derived from two way fixed effects ANOVA of effects of tide (high vs low) and diel period (day vs night) for Gerres ovatus, *Gobiidae and sample totals. Data tested for heteroscedasticity using Cochran's test ($p < 0.1$). A = log transformed data, B = raw data*

Source of Variance	df	F ratio		
		Gerres ovatus[A]	Gobiidae[B]	Sample Totals[B]
Tide	1	16.10**	5.17*	0.08 NS
Diel	1	12.55**	19.11***	11.71**
TxD	1	1.85 NS	0.06 NS	0.08 NS
Residual	12			

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, NS $p > 0.05$

DISCUSSION

Gerres ovatus larvae were significantly more abundant on high tides whilst gobiid larvae were caught in significantly greater numbers during low tides. As *G. ovatus* and numerous gobiid species are known to spawn within Botany Bay (State Pollution Control Commission, 1981) their centres of larval abundance may have been expected to coincide. Yet, they have become spatially separated, occurring at either end of the tidal range. This larval distribution was found both during daylight and at night. Two hypotheses, not mutually exclusive, to explain this are: (1) spawning aggregations of *G.*

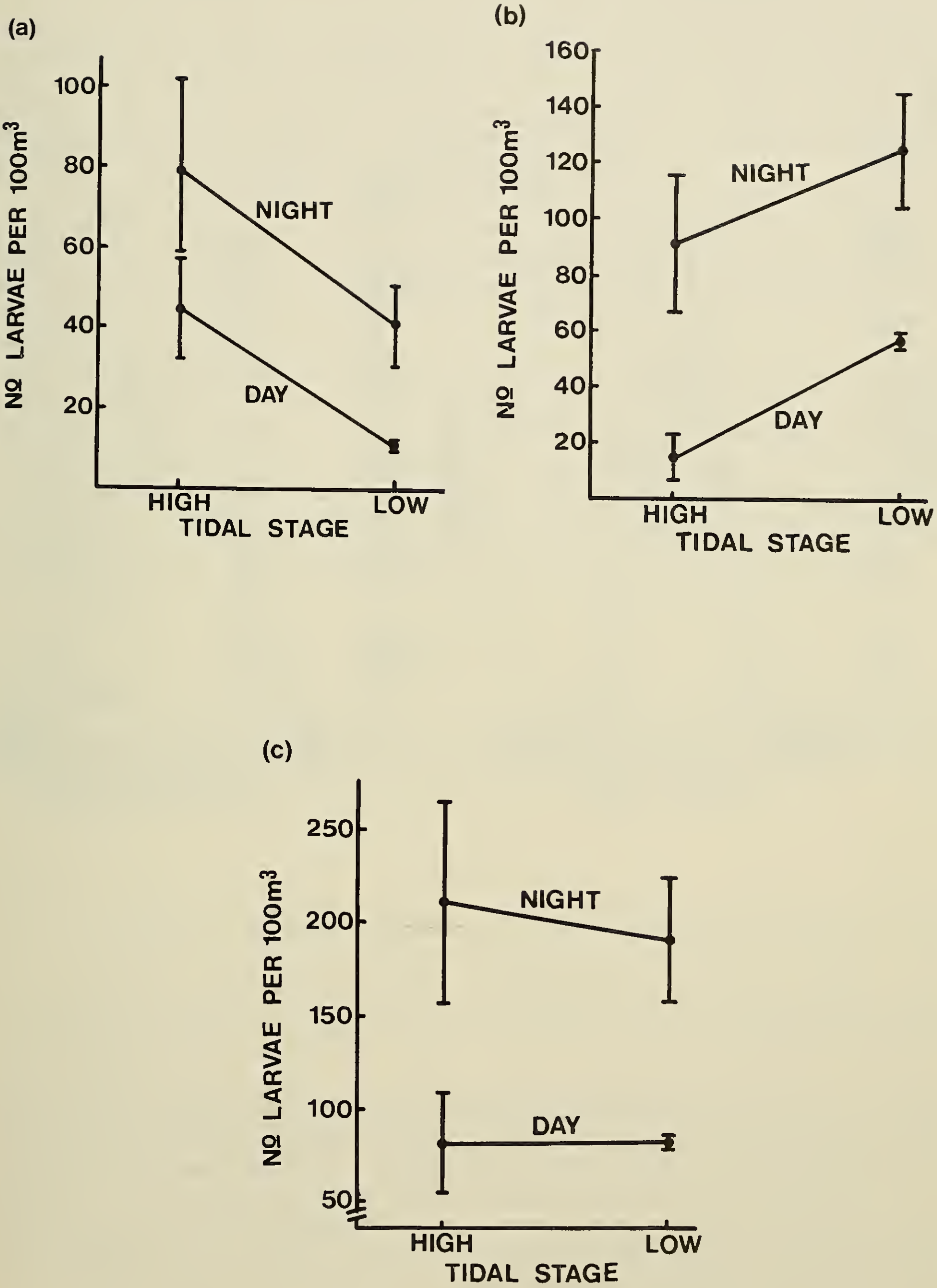

Fig. 2. Mean and ± one SE for the standardized larval abundances at each of the consecutive tides, both day and night, over the 24 hour sampling period for (a) *Gerres ovatus*, (b) Gobiidae, and (c) sample totals.

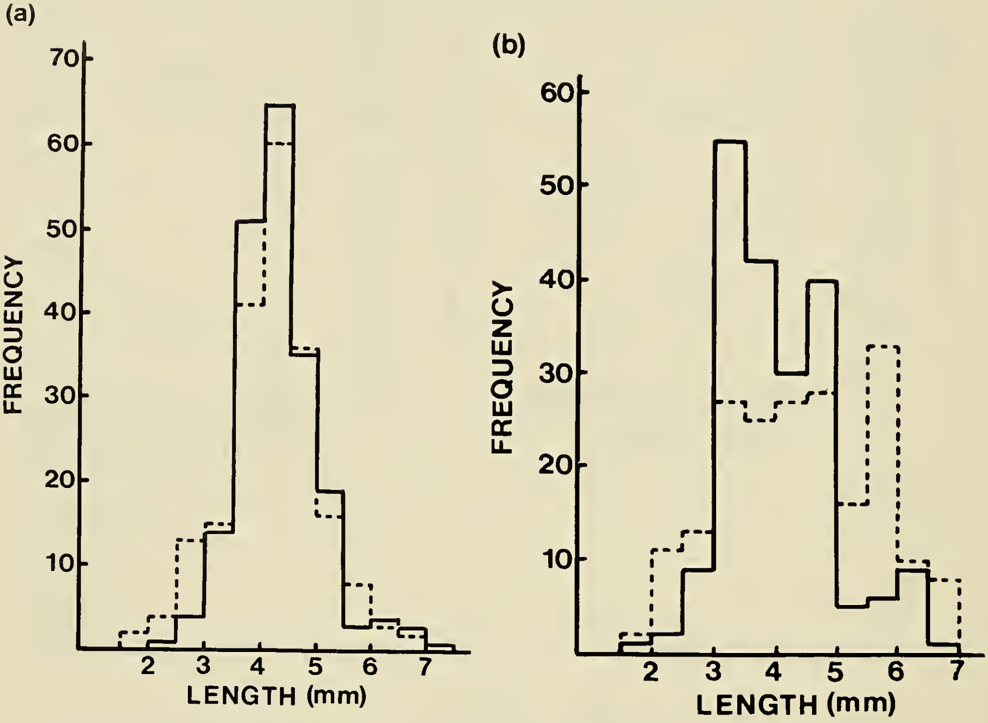

Fig. 3. Length frequencies of randomly selected day-caught (n = 200) and night-caught (n = 200) larvae for (a) *Gerres ovatus*, and (b) Gobiidae. Solid lines denote day-caught, and broken lines denote night-caught.

ovatus occur near the Bay entrance and seaward of gobiid spawning sites; and (2) both groups spawn at a similar distance into the Bay, but the demersal eggs of gobiids are more effective than the pelagic eggs of *G. ovatus* at reducing the net transport of offspring seaward from spawning sites by currents. This could occur because demersal eggs, unlike pelagic eggs, are not subject to passive transportation by currents, and because at hatching, larvae from demersal eggs tend to be relatively larger, more developed, with better swimming capabilities than those from pelagic eggs (Steffe and Pease, 1988).

Larval catches of *Gerres ovatus* and gobiids were found to be significantly greater at night (Table 2). There was no difference in the size structure of *G. ovatus* between day and night (Fig. 3a) suggesting that differential net avoidance was minimal and that the higher night catches could be mainly attributed to the effects of diel vertical migration.

The effects of differential net avoidance and diel vertical migration could not be separated for gobiids as more large larvae were caught at night (Fig. 3**b**).

Most *Gerres ovatus* larvae had deflated gas bladders during the day whilst the reverse was true at night. This phenomenon appears to be common and occurs in many taxonomically diverse teleost groups (Hunter and Sanchez, 1976; Leis and Rennis, 1983; Liew, 1983; Hoss and Phonlor, 1984; Kitajima *et al.*, 1985; A. Steffe, unpub. data). Hunter and Sanchez (1976) found that nocturnal gas bladder inflation can provide considerable energy savings to northern anchovy *Engraulis mordax* larvae by retarding sinking. It is likely that larval *G. ovatus* gain a similar benefit.

The silverbiddy, *G. ovatus*, has been found to recruit almost exclusively to mangrove areas in Botany Bay (State Pollution Control Commission, 1981). The observed larval distribution of *G. ovatus* at a site near its preferred nursery habitat supports the hypothesis that larval silverbiddy may be using flood tides to assist their transportation into mangrove areas. This hypothesis appears tenable because mangrove areas are wholly dependent on tide for water exchange.

The data presented and interpreted here are based on collections made during a single 24 hour period. Consequently, it is possible that the effects of other variables which were not specifically tested may have, by chance, been confounded with the effects of the tidal and diel factors examined during the selected sampling day; in view of the relatively constant temperature and salinity conditions it is unlikely that larval catches were influenced by these parameters. Further sampling, that is, the same experiment repeated on other 'replicate' days, is required to eliminate this possible source of error and to possibly allow the conclusions drawn here to be accepted with greater confidence.

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